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(54) Method for etching metal silicide with high selectivity to polysilicon

(57) A method for etching metal silicide layers **22a**, **22b** and polysilicon layers **24a**, **24b** on a substrate **20** with high etching selectivity and anisotropic etching properties is described. In the method, the substrate **20** is placed in a plasma zone **55** and process gas comprising Cl_2 , O_2 and N_2 is introduced into the plasma

zone. A plasma is formed from the process gas to selectively etch the metal silicide layer **22** at a first etch rate that is higher than a second rate of etching of the polysilicon layer **24** while providing substantially anisotropic etching of the metal silicide and polysilicon layers. Preferably, the plasma is formed using combined inductive and capacitive plasma sources.

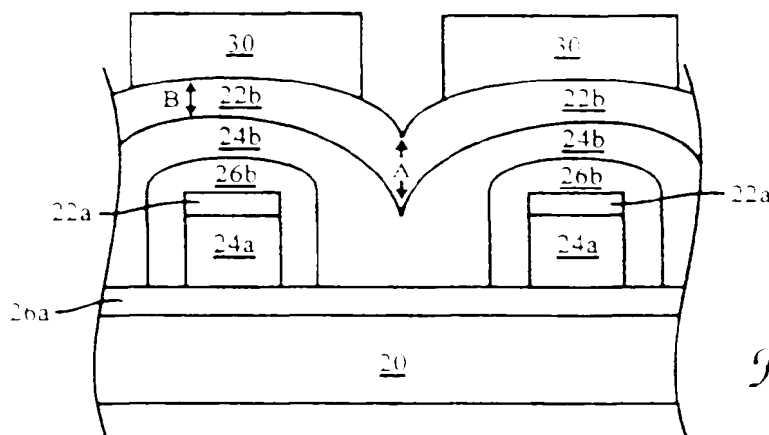


Fig. 1c

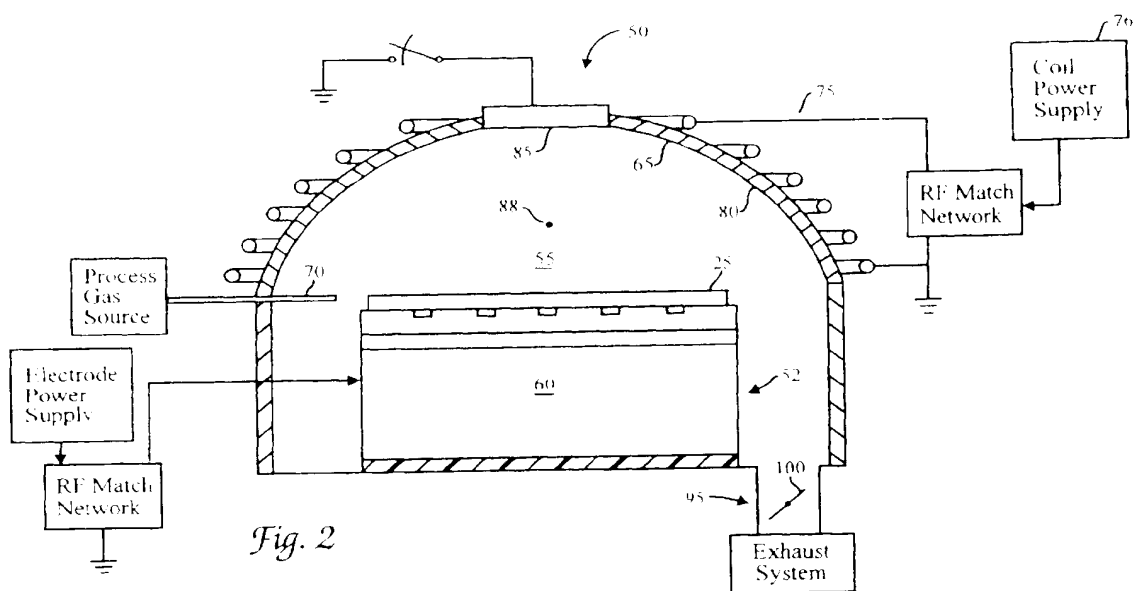


Fig. 2

Description

The present invention relates to a method for etching metal silicide layers during processing of semiconductor substrates.

In integrated circuit fabrication, refractory metal silicides, such as, for example, for osmium, tantalum, titanium, and molybdenum silicides, are used to form high density, high speed, highly electrically conductive interconnect features and lines for electrically connecting devices formed on semiconductor substrates. For example, WSi₂ layers can be deposited on silicon dioxide to serve as gate electrodes for integrated circuits. However, at the silicide and oxide interface, diffusion of silicon from the SiO₂ layer into the refractory metal silicide layer causes the metal silicide layer to have unacceptably high electrical resistance. "Polyicide" stacks were developed to reduce the diffusion problems with metal silicide layers. With reference to Figure 1a, typical polyicide structures on a semiconductor substrate **20** comprise refractory metal silicide layers **22a**, **22b** deposited over doped or undoped polysilicon layers **24a**, **24b**. The polyicide structures are formed over silicon dioxide layers **26a**, **26b** on the substrate **20** and provide a low electrical resistance interconnect with excellent interfacial characteristics.

In conventional methods of fabricating the polyicide interconnect structures, the metal silicide layers **22** are deposited over polysilicon layers **24**. For example, commonly assigned U.S. Patent No. 5,503,249, to Telford et al., incorporated herein by reference, describes a chemical vapor deposition process for depositing WSi₂ films on polysilicon via plasma enhanced chemical vapor deposition of tungsten hexafluoride and dichlorosilane. After deposition of the metal silicide layer **22**, photoresist material is applied on the polyicide layers and exposed to light to form a desired pattern of interconnect features using conventional photolithographic processes. The patterned resist **30** serves as a mask for etching of the polyicide structure using conventional etching processes to provide the shape of the etched feature **40** illustrated in Figure 1b. Thereafter, the deposition and etching process can be repeated to form additional layers of polyicide stacks, as illustrated in Figures 1c and 1d.

Conventional etching processes use a microwave or capacitive plasma of halogen-containing gases to etch the polyicide stack. Commonly used fluorinated etchant gases include CF₄, SF₆, and NF₃; chlorine-containing etchant gases include CCl₄ and BCl₃; and bromine-containing etchant gases include HBr. One problem with conventional etching processes is their relative inability to provide high etching selectivity ratios for etching metal silicide with respect to polysilicon, while simultaneously forming anisotropically etched feature profiles.

The etching selectivity ratio is the ratio of the rate of etching of the metal silicide layer **22** to the rate of etching of the underlying polysilicon layer **24**. It is particularly

desirable to have high etching selectivity ratios for polyicide structures having a non-planar and highly convoluted topography, as schematically illustrated in Figure 1c. In these structures, the portion of the conformal metal silicide layer **22b** between the etched features as shown by the arrow A is thicker than the portion of the metal silicide layer **22b** on top of the etched features as shown by the arrow B. Thus, at a certain time during the etching process, at the portion B the metal silicide layer is etched through and etching of the underlying polysilicon layer begins, while at the portion A, the thicker metal silicide layer **22** is still being etched. This effect requires that the polysilicon layer **24b** at the portion B be etched sufficiently slowly relative to the rate of etching of the silicide layer, that the entire polysilicon layer **24b** at portion B is not etched through, before completion of etching of the thicker portions of the convoluted metal silicide layer **22b** at portion A. Thus, it is desirable to etch the metal silicide layer **22** at a faster rate relative to the rate of etching of the polysilicon layer **24**.

High etching selectivity ratios are obtained by using process gas compositions that etch different materials at different etching rates, depending upon the chemical reactivity of the process gas with the different materials. However, etching metal silicide with high selectivity to polysilicon is particularly difficult, because both materials contain elemental silicon, and most conventional etchant plasmas etch the silicon portion to form gaseous SiCl₄ or SiF₄ species. Thus, it is difficult for the etchant plasma to chemically distinguish and preferentially etch the metal silicide layer **22** faster than the polysilicon layer **24**. Also, the more chemically active plasma etching processes, such as ECR and/or microwave plasma processes, provide more dissociated chemically active etchant species, and result in isotropic etching of the silicide layers, as described below.

It is also desirable to etch the polyicide stack to form anisotropically etched features **40**, which result when the metal silicide and polysilicon layers are etched substantially vertically to provide features having straight sidewalls **48**. Excessive etching at the sidewalls **48** of the etched features results in undesirable inwardly or outwardly sloped walls. A degree of anisotropic etching is obtained when dissociated species in the etchant gas combine to form complex polymeric byproducts that deposit as "passivating" layers on the sidewalls of freshly etched features **40** and serve to limit further etching of the sidewalls **48**. More typically, anisotropic etching is obtained by imparting a highly directional kinetic energy to the charged species in the etchant plasma by subjecting the plasma to an electric field perpendicular to the substrate **20**, that causes the plasma species to energetically impinge upon and remove substrate material in the vertical etching direction. However, different materials are sputter etched by the highly energized plasma at the same etch rate providing little or no control over etching selectivity. For these reasons, it is difficult to obtain anisotropic etching in combination with high

etching selectivity ratios for etching metal silicide on polysilicon

Thus, it is desirable to have an etching process for etching polycide structures with high etching selectivity and in particular, for etching metal silicide layers at faster etch rates than polysilicon. It is further desirable for the etching process to provide substantially anisotropic etching, and to provide uniform etching rates across the surface of the substrate.

The present invention is directed to a method of etching polycide structures comprising metal silicide and polysilicon layers substantially anisotropically and with high etching selectivity. In the method, a substrate is placed in a plasma zone, and process gas comprising Cl_2 , O_2 , and N_2 is introduced into the plasma zone. A plasma is formed from the process gas to selectively etch the metal silicide layer at a first etch rate that is higher than a second rate of etching of the polysilicon layer, while providing substantially anisotropic etching of the metal silicide and polysilicon layers.

Preferably, the etchant plasma is formed using combined inductive and capacitive plasma sources, for example, in a process chamber comprising an inductor coil and process electrodes. A process gas comprising Cl_2 , O_2 , and N_2 is ionized in the chamber to form plasma ions that energetically impinge on the substrate by (i) applying an RF current at a first power level to the inductor coil, and (ii) applying an RF voltage at a second power level to the process electrodes. A power ratio P_1 of the first power level to the second power level is selected to provide highly selective etching of the metal silicide layer relative to the polysilicon layer, while providing substantially anisotropic etching of both layers.

Preferably, the gas composition and power ratio P_1 of the plasma are selected so that the etch rate of the metal silicide layer is at least 1.2 times the etch rate of the polysilicon layer, and the metal silicide and polysilicon layers are etched to form features that have sidewalls that form angles of at least about 88° with a surface of the substrate. Preferably, the volumetric flow ratio of O_2/N_2 is from about 0.25 to about 5:1, and the ratio of the volumetric flow of Cl_2 to the combined volumetric flow of O_2 and N_2 is from about 5:1 to about 20:1. More preferably, the power ratio P_1 of the first power level to the second power level is from about 0.1:1 to about 100:1.

These and other features, aspects, and advantages of the present invention will become better understood from the following drawings and description, which show and describe examples of the invention, and from the appended claims, where:

Figure 1a is a schematic in vertical cross-section of a polycide stack comprising a metal silicide layer deposited over a polysilicon layer on a semiconductor substrate.

Figure 1b is a schematic in vertical cross-section of

the substrate of Figure 1a after etching of the metal silicide and polysilicon layers showing substantially anisotropically etched features.

Figure 1c is a schematic in vertical cross-section of a non-planar and highly convoluted topography of a metal silicide layer deposited over a polysilicon layer on a substrate.

Figure 1d is a schematic in vertical cross-section of the substrate of Figure 1c after etching of the metal silicide and polysilicon layers showing substantially anisotropically etched features.

Figure 2 is a schematic view in vertical cross-section of a process chamber suitable for practicing the etching process of the present invention.

Figure 3 is a graph showing the WSi_x etch rate for increasing O_2 and N_2 flow rates.

Figure 4 is a graph showing the polysilicon etching rate for increasing flow rates of O_2 and N_2 .

Figure 5 is a graph showing the etching selectivity ratios of etching WSi_x relative to polysilicon for increasing flow rates of N_2 and O_2 in the process gas.

Figure 6 is a graph showing the etching selectivity of etching WSi_x relative to doped polysilicon for increasing Si/W ratio in the WSi_x film, and

Figure 7 is a graph showing the etching selectivity of etching WSi_x relative to undoped polysilicon for increasing Si/W ratio in the WSi_x film.

The etching process of the present invention is useful for etching a substrate 20 having polycide stacks comprising metal silicide layers 22a, 22b on underlying polysilicon layers 24a, 24b as shown in Figures 1a-1d, with high etching selectivity, good etch rates, and anisotropic etching. The substrate 20 can be made of any material, such as glass, ceramic, metal, polymer, or semiconductor substrate, such as a silicon or gallium arsenide wafers. The metal silicide layer 22 on the substrate 20 typically comprises, for example, tungsten, tantalum, titanium, or molybdenum silicides, having a thickness of about 500 Å to about 10000 Å. The polysilicon layer 24 below the metal silicide layer 22 also typically comprises a thickness of about 500 Å to about 10000 Å. The polycide stack is deposited on a silicon dioxide layer 26 having a thickness of about 1000 Å.

The metal silicide and polysilicon layers 22, 24 are etched to form electrical interconnect lines on the substrate 20. Typically, photoresist 30 such as "RISTON" manufactured by DuPont de Nemours Chemical Company is applied on the metal silicide layer 22 to a thickness of about 0.4 to about 1.3 micron, and the features

40 to be etched in the metal silicide and polysilicon layers are defined using conventional lithographic processes in which the resist 30 is exposed to a pattern of light through a mask that corresponds to the desired configuration of features 40. The etched features 40 are typically sized from about 0.2 to about 10 microns, and more typically about 0.4 to 2 microns, and the spacing between the features is typically from 0.2 microns to 10 microns. During the etching process, polymeric passivating deposits 44 form on the sidewalls 48 of the etched features 40, as explained below.

The metal silicide layer 22 and polysilicon layer 24 are etched in a process chamber 50, such as for example a "QIPS" chamber schematically illustrated in Figure 2, and commercially available from Applied Materials Inc., Santa Clara, California. The process chamber is also described in EP-A-9750069, entitled "RF Plasma Reactor with Hybrid Conductor and Multi-Radius Dome Coiling", and EP-A-0727507, both of which are incorporated herein by reference. The particular embodiment of the process chamber 50 shown herein is suitable for processing of semiconductor substrate 20, is provided only to illustrate the invention, and should not be used to limit the scope of the invention. For example, the etching process of the present invention can be used to etch any substrate, and can be used for manufacturing processes other than semiconductor fabrication.

To perform the process, the chamber 50 is evacuated to a pressure of less than 1 Torr, and a substrate 20 is placed on a support 52 within a plasma zone 55 in the chamber. The substrate 20 can be held in place during the etching process using a mechanical or electrostatic chuck with grooves in which a coolant gas, such as helium, is held to control the temperature of the substrate 20. At least a portion of the support 52 is electrically conductive and serves as a process cathode electrode 60. The cathode electrode 60, in conjunction with sidewalls of the chamber 50 that are electrically grounded to serve as an anode electrode 65, form process electrodes in the plasma zone 55.

Process gas is introduced into the chamber 50 through a gas distributor 70 peripherally disposed about the substrate 20, and the chamber is maintained at a pressure ranging from about 0.1 to about 100 mTorr, and more typically from 2 to 10 mTorr. A plasma is formed from the process gas using a plasma generator that couples an electric field into the plasma zone 55. The plasma generator can comprise an inductor coil 75 adjacent to the process chamber 50, and capable of forming an inductive electric field in the chamber when powered by a coil power supply 76. Preferably, an RF current at a first power level is applied to the inductor coil 75, the first power level being preferably from about 200 Watts to about 2000 Watts.

In addition to the inductor coil, the cathode and anode electrodes 60, 65, powered by an electrode power supply 78, are used to generate a capacitive electric field in the process chamber 50. Typically, an RF voltage at

a second power level, of from about 100 to about 2000 Watts, is applied to the cathode electrode 60, and the anode electrode 65 is electrically grounded. The capacitive electric field is perpendicular to the plane of the substrate 20, and accelerates inductively formed plasma species toward the substrate 20 to provide more vertically oriented anisotropic etching of the substrate. The frequency of the RF voltage applied to the process electrodes 60, 65, and/or the inductor coil 75 is typically from about 50 KHz to about 60 MHz, and more typically about 10-50 MHz.

It is preferred to use a process chamber 50 having a quasi-remote plasma zone 55 to obtain optimal etching properties. The quasi-remote plasma zone 55 is within the region bounded by the substrate 20, the chamber sidewalls 80 adjacent to the substrate, and the ceiling 85 of the chamber having an apex at a height H of from about 100 mm to about 175 mm (4 to 7 inches) above the substrate 20. It should be noted that the ceiling height can vary for different sized substrate; the ceiling height described herein being suitable for substrate having diameters of from about 150 mm to about 304 mm (6 to 12 inches). Preferably, the quasi-remote plasma zone 55 comprises a volume of at least about 10,000 cm³, and more preferably from about 10,000 to about 50,000 cm³. In the quasi-remote plasma zone, the plasma is formed directly below the ceiling 85 and immediately above the substrate 20. Preferably, the quasi-remote plasma zone 55 has a center 88 located at a distance of about 50 to about 150 mm directly above the substrate 20, and more preferably at a distance that is greater than about 75 mm and less than about 125 mm from the substrate 20.

It is believed that the quasi-remote plasma zone 55 provides an increased amount of dissociated etchant cations relative to non-dissociated cations, because the plasma is generated in a relatively large volume of space immediately adjacent to the substrate 20. This feature allows the plasma to etch the substrate 20 before a large amount of the dissociated ions/cations recombine to form non-dissociated cations. In the center 88 of the plasma zone 55 is remote from the substrate 20, for example at a distance of greater than about 30 cm, the dissociated plasma ions recombine to form non-dissociated ions while traveling from the remote plasma source to the substrate 20. Conversely, if the center 88 of the plasma zone 55 is too close to the substrate 20, i.e., less than about 10 cm, the high power current applied to the plasma generator to increase dissociation of the plasma ions causes the plasma ions to have excessively high kinetic energies which results in poor etching performance. Similarly, if the volume of the plasma zone 55 is excessively large, the dissociated ions in the plasma zone recombine to form non-dissociated species. Also, if the volume of the plasma zone 55 is too small, it is difficult to form dissociated plasma ions because the mean free path of the energized inert gas ions is excessively small, resulting in fewer collisions

sions between the inert gas ions and the etchant gas molecules. For these reasons, it is preferred to use the quasi-remote plasma zone **55**.

The ceiling **85** of the process chamber **50** can be flat or rectangular shaped, arcuate, conical, dome-shaped, or multi-radius dome-shaped. Preferably the process chamber **50** has a multi-radius dome-shaped ceiling **85** above the substrate **20** to provide a uniform distribution of plasma source power across the entire volume of the plasma zone **55** to increase dissociation of the etchant gas, as for example described in EP-A-97300554.9, entitled "PLASMA PROCESS FOR ETCHING MULTICOMPONENT ALLOYS", filed on February 5, 1996, which is incorporated herein by reference. The multi-radius dome-shaped ceiling **85** reduces dissociated ion recombination losses near the substrate **20** to less than those experienced with a flat ceiling, so that plasma ion density is more uniform across the substrate **20**. This is because ion recombination losses are affected by the proximity of the ceiling **85**, and the dome-shaped ceiling is further from the substrate center than a flat ceiling.

Preferably, the inductor coil **75** is wrapped around the sidewall **80** of the process chamber **50** in the form of a multi-radius dome-shaped inductor coil having a "flattened" dome shape that provides more efficient use of plasma source power and increased plasma ion density directly over the substrate center. This is because ion density is affected by local ionization near the inductor coil **75**, and a multi-radius inductor coil is closer to the substrate center than a hemispherical coil. In another preferred embodiment, the ceiling **85** comprising a multi-radius dome having at least a center radius R and a corner radius r less than the center radius R , wherein R/r is from about 2 to about 10.

The plasma formed in the quasi-remote plasma zone **55** can also be enhanced using magnetically enhanced reactors, in which a magnetic field generator, such as a permanent magnet or electromagnetic coils, are used to apply a magnetic field in the plasma zone **55** to increase the density and uniformity of the plasma. Preferably the magnetic field comprises a rotating magnetic field with the axis of the field rotating parallel to the plane of the substrate **20**, as described in U.S. Patent No. 4,842,683, issued June 27, 1989, which is incorporated herein by reference. The magnetic field in the chamber **50** should be sufficiently strong to increase the density of the ions formed in the plasma, and sufficiently uniform to reduce charge-up damage to features such as CMOS gates. Generally the magnetic field as measured on a surface of the substrate is less than about 500 Gauss, more typically from about 10 to about 100 Gauss, and most typically from about 10 Gauss to about 30 Gauss.

Spent process gas and etchant byproducts are exhausted from the process chamber **50** through an exhaust system **95** capable of achieving a minimum pressure of about 10^{-3} mTorr in the process chamber **50**. A

throttle valve **100** is provided in the exhaust for controlling the pressure in the chamber **50**. Also, an optical endpoint measurement technique is often used to determine completion of the etching process for a specific layer by measuring the change in light emission of a particular wavelength corresponding to a detectable gaseous species. A sudden decrease or increase in the amount of the detectable species, such as silicon species, that results from chemical reaction of the process gas with the silicon dioxide layer **26**, indicates completion of etching of the metal silicide layer **22** and start of etching of the underlying layer.

The etching process of the present invention provides high etch rates, and highly selective etching of metal silicide relative to polysilicon. The process gas used in the etching process comprises (i) chlorine, (ii) oxygen, and (iii) nitrogen. The chlorine gas forms dissociated atomic chlorine and chlorine-containing species that etch the metal silicide layer **22** and polysilicon layer **24** on the substrate **20**. For example, silicon in the metal silicide and polysilicon layers **22**, **24** can be etched by chlorine-containing ions and neutrals to form volatile Si-Cl_x species that are exhausted from the chamber **50**. The chlorine gas can comprise Cl_2 , or can comprise other chlorine-containing gases that are equivalent to chlorine, for example, HCl , BCl_3 , and mixtures thereof.

The oxygen gas, for example, O_2 , Cl_3 , and other equivalent oxygen-containing gases, is used to enhance the rate of etching of metal silicide layer **22** without increasing the rates of etching of silicon-containing underlayers, such as the polysilicon layer **24**. However, excessively high flow rates of the oxygen gas can cause more isotropic etching of the substrate by removing the passivating deposits **44** formed on the etched features, and can also result in excessively low dielectric etch rates. For these reasons, the flow rate of oxygen gas is maintained lower than the flow rate of the chlorine gas to provide sufficient chlorine-containing species to rapidly etch the substrate **20**, while providing high silicide to silicon etching selectivity and anisotropic etching.

The nitrogen gas provides unexpected results in combination with the chlorine and oxygen gases. Increasing the nitrogen gas significantly lowers the rate of etching of polysilicon layer **24**, without affecting the rate of etching of the metal silicide layer **22**. It is believed that the chlorine, nitrogen, and oxygen gas, react with metal silicides to form volatile byproducts (for example, when etching tungsten silicide layers, volatile species such as $\text{W}_x\text{O}_y\text{N}_z\text{Cl}$ or $\text{W}_x\text{O}_y\text{N}_z$ are formed) that serve to increase the rate of etching of the MSi_x layer relative to the rate of etching of the polysilicon layer **24**. Because the atomic and molecular constituents of an active plasma are difficult to analyze, the nature or composition of the metal-containing volatile species is difficult to determine with accuracy. It is also believed that the combination of nitrogen and oxygen serve to balance the rate of deposition and removal of the passivating deposits on the etched features of the substrate to provide more aniso-

the rate of etching of the substrate **20**. The process gas preferably comprises N_2 or other nitrogen-containing gases equivalent to N_2 such as NO or N_2O .

The unexpected results provided by the Cl_2 - Cl_2 - N_2 processes are demonstrated by Figures 3-5 which show the effect of increasing Cl_2 and N_2 flow rates on the rate of etching of a metal silicide layer comprising WSi_2 and the etch rate of a polysilicon layer. Figure 3 shows the WSi_2 etch rate for increasing Cl_2 and N_2 flow rates. It is observed that increasing N_2 flow rates has little effect on the WSi_2 etch rate. In contrast, increasing Cl_2 flow rates from 0 sccm to 10 sccm increases the WSi_2 etch rates from 250 nm/min to 350 nm/min. Thus, addition of Cl_2 and N_2 to the Cl_2 gas provides the unexpected results of increasing WSi_2 etch rates while simultaneously decreasing the polysilicon etch rates, even though both materials contain elemental silicon. This result provides increased etching selectivity rates for etching WSi_2 relative to polysilicon while simultaneously providing higher WSi_2 etching rates, which is a highly desirable combination.

Figure 4 shows the polysilicon etching rate for increasing flow rates of Cl_2 and N_2 . Generally, the polysilicon etch rate is lowered for increasing flow rates of Cl_2 as well as increasing flow rates of N_2 . Thus, the addition of Cl_2 and N_2 to the chlorine gas serves primarily to improve the etching selectivity ratio of etching WSi_2 relative to polysilicon by decreasing the rate of etching of polysilicon. Figure 5 shows the etching selectivity ratios of etching WSi_2 relative to polysilicon for increasing flow rates of N_2 and Cl_2 in the process gas. It is observed that the etching selectivity ratios increase for both increasing flow rates of Cl_2 and increasing flow rates of N_2 . Thus, both Cl_2 and N_2 contribute to enhanced selectivity etching ratios.

The composition and volumetric flow ratios of different constituents of the process gas are selected to etch the metal silicide layer **22** faster than the polysilicon layer **24**, preferably at an etching selectivity ratio of at least about 1:2, and more preferably at least about 1:5. The volumetric flow ratio of the process gas is also selected to provide anisotropically etched features having side walls **48** with smooth surfaces that form angles relative to a plane of the substrate **20**, and more preferably angles from about 55° to about 90° . Preferred volumetric flow ratios of Cl_2 - N_2 are from about 0.25 to about 5:1, and more preferably from about 0.5:1 to about 3:1. Preferably, the ratio of the volumetric flow of Cl_2 to the combined volumetric flow of Cl_2 and N_2 is from about 5:1 to about 20:1, and more preferably from about 7:1 to about 15:1.

For the size of the process chamber described herein, the flow rate of Cl_2 is preferably from about 10 to about 800 sccm, the flow rate of N_2 is from about 4 to about 60 sccm, and the flow rate of Cl_2 is from about 0.1 to about 40 sccm. Preferably, the flow rate of N_2 is maintained within about 20 sccm of the flow rate of Cl_2 , and more preferably, the flow rate of Cl_2 and the flow

rate of N_2 both range from about 1 to about 50 sccm. It should be understood that the flow rates are dependent upon the size of the process chamber and equivalent flow rates for different sized chambers are contemplated within the scope of the present invention.

The power ratio P_1 of the first current power level to inductor coil **75** to the second voltage power level to the process electrodes **60, 65** is also selected to enhance the ability of the etchant plasma to anisotropically etch the metal silicide layer **22** with high selectivity relative to the polysilicon layer **24**. A high power ratio P_1 , obtained by increasing the first power level of the current applied to the inductor coil **75**, increases the amount of dissociated etchant species to provide faster and more isotropic etching. Conversely, a low power ratio P_1 , obtained from a low first power level to the coil, can cause insufficient dissociation of the etchant gas into dissociated ions resulting in low etch rates and low etching selectivity. Increasing the second power level of the RF voltage applied to the process electrodes **60, 65** increases the degree of anisotropic etching of the metal silicide layer **22** by providing a higher kinetic bombardment energy component to the plasma. However, an excessively high second power level, that also provides a low power ratio P_1 , can cause sputtering of the substrate **20** and result in non-uniform etching of the substrate. It has been discovered that a preferred power ratio P_1 is at least about 0.1:1, and more preferably from about 0.1:1 to about 100:1. Most preferably, the plasma is formed by applying a current at a first power level of about 200 to 2000 Watts to the inductor coil **75** adjacent to the plasma zone **55**, and the plasma is attracted to the substrate **20** by applying a voltage at a power level of about 5 to 500 Watts to process electrodes **60, 65** in the plasma zone.

The following examples illustrate use of the present invention for etching metal silicide layers on semiconductor substrate. However, the apparatus and method can be used in other applications as would be apparent to those skilled in the art, and the scope of the present invention should not be limited to the illustrative examples provided herein.

In these examples, the etching processes were performed on silicon substrate having a diameter of 200 mm in inches. Each substrate comprised a top 400 Å thick layer of WSi_2 , a middle 4000 Å thick layer of polysilicon, and a lower 1000 Å SiO_2 layer deposited on the monocrystalline silicon substrate. The WSi_2 layer on the substrate comprised either of two different Si/W ratios of about 2:1 or about 2.96:1, and comprised either a doped polysilicon layer or an undoped polysilicon layer. The different Si/W ratios were used to determine the variation of etching rates for WSi_2 layers having different Si/W ratios. The substrate were etched in a "DFS" process chamber having the configuration described above, and the support **52** in the chamber was maintained at a temperature of 50°C.

SEM photos of the etched wafers were used to

measure (i) the metal silicide or polysilicon etch rate, (ii) the etching selectivity ratio of etching metal silicide relative to polysilicon, and (iii) the sidewall 48 profile angle. Etch rates were calculated by measuring the step height or depth of the etched features 40 observed in the SEM photographs. The etching selectivity ratio was calculated from the ratio of the etch rate of the metal silicide layers to the etch rate of the polysilicon layer 24

Examples 1 and 2 demonstrate an etching process of the present invention that used a process gas comprising 130 sccm Cl_2 , 5 sccm O_2 , and 18 sccm N_2 , and the pressure in the chamber was maintained at 4 mTorr. The plasma was formed by applying a RF current at a first power level of 1400 Watts to the inductor coil, and the process electrodes were biased using a RF voltage at a second power level of 100 Watts. In Example 1, the WSi_x layer on the substrate comprised an Si:W ratio of about 2:1:1. In Example 2, the WSi_x layer on the substrate comprised an Si:W ratio of about 2:98:1.

Figure 6 shows the etching selectivity ratio for etching WSi_x films relative to doped polysilicon for the increasing Si:W ratio of the WSi_x films of Examples 1 and 2. It is observed that the $\text{Cl}_2/\text{O}_2/\text{N}_2$ process gas provide relatively uniform etching selectivity ratios of about 1.8 over the entire range of Si:W stoichiometric ratios. Figure 7 shows the etching selectivity ratio for etching WSi_x films relative to undoped polysilicon for increasing Si:W ratio in the WSi_x film for Examples 1 and 2. It is observed that the $\text{Cl}_2/\text{O}_2/\text{N}_2$ process gas provide relatively uniform etching selectivity ratios ranging from about 4 to 5, for the entire range of Si:W stoichiometric ratios. The uniformity of the etching selectivity ratios over a wide range of Si:W ratios in both the doped and undoped polysilicon provides process reproducibility for etching WSi_x layers having varying Si:W ratios.

Although the present invention has been described in considerable detail with regard to the preferred version thereof, other versions are possible. Therefore, the appended claims should not be limited to the description of the preferred versions contained herein.

Claims

1. A method for anisotropically etching metal silicide and polysilicon layers on a silicon wafer or other substrate, the method comprising the steps of placing the substrate in a plasma zone, and forming a plasma from process gas introduced into the plasma zone to etch the metal silicide and polysilicon layers on the substrate, characterized in that the process gas comprises Cl_2 , O_2 , and N_2 .
2. A method according to claim 1 characterized in that the plasma is formed from the process gas by applying RF current at a first power level to the inductor coil, and applying RF voltage at a second power level to the process electrodes, the power ratio P_1 of the first power level to the second power level being selected so that the metal silicide layer is etched at a first etch rate that is at least 1.2 times a second rate of etching of the polysilicon layer.
3. A method for anisotropically etching metal silicide and polysilicon layers on a silicon wafer or other substrate, the method comprising the steps of placing the substrate in a process chamber comprising process electrodes and an inductor coil, and forming a plasma from process gas introduced into the process chamber to etch the metal silicide and polysilicon layers on the substrate, characterized in that:
 - (1) the process gas comprises Cl_2 , O_2 , and N_2 and
 - (2) the plasma is formed from the process gas by applying RF current at a first power level to the inductor coil, and applying RF voltage at a second power level to the process electrodes, the power ratio P_1 of the first power level to the second power level being selected so that the metal silicide layer is etched at a first etch rate that is at least 1.2 times a second rate of etching of the polysilicon layer.
4. A method according to claims 2 or 3 characterized in that the power ratio P_1 of the first power level to the second power level is from 0.1:1 to 100:1.
5. A method according to claim 4 characterized in that the first power level is from 200 to 2000 Watts, and the second power level is from 5 to 500 Watts.
6. A method according to any one of the preceding claims characterized in that:
 - (1) the volumetric flow ratio of O_2 to N_2 is from 0.25 to 5:1, or
 - (2) the ratio of the volumetric flow of Cl_2 to the combined volumetric flow of O_2 and N_2 is from 5:1 to 20:1.
7. A method according to any one of the preceding claims characterized in that volumetric flow ratio of O_2 to N_2 is from 0.5:1 to 3:1, and the ratio of the volumetric flow of Cl_2 to the total volumetric flow of O_2 and N_2 is from 7:1 to 15:1.
8. A method according to any one of the preceding claims characterized in that the flow rate of Cl_2 is from 20 to 800 sccm, the flow rate of N_2 is from 4 to 60 sccm, and the flow rate of O_2 is from 0.1 to 40 sccm.
9. A method according to any one of the preceding

claims characterized in that the process gas consists essentially of C_2H_4 , C_2H_2 and N_2 .

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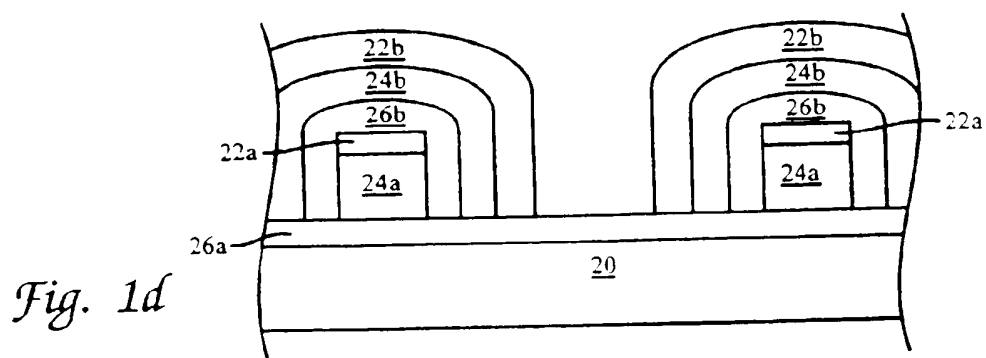
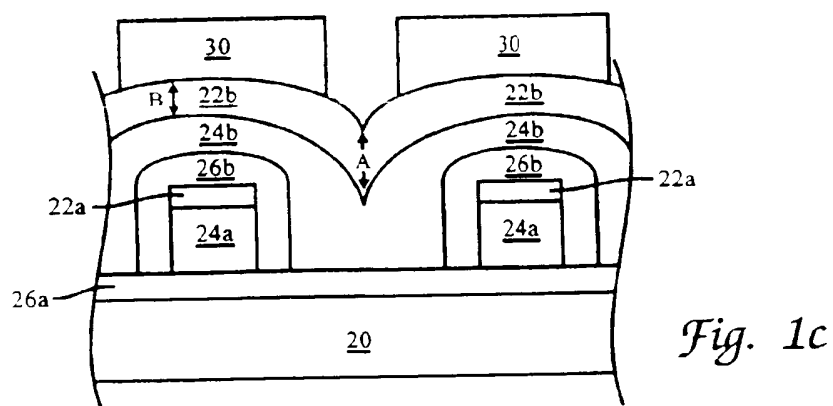
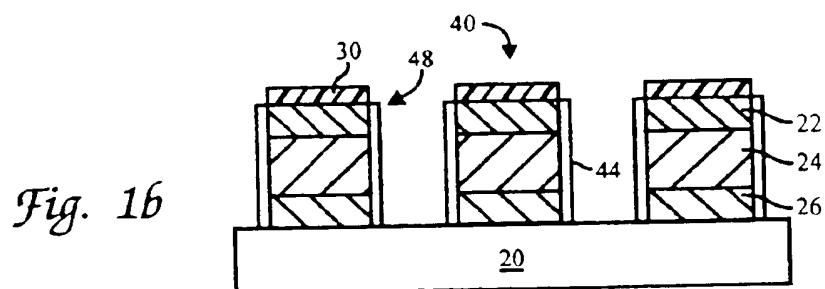
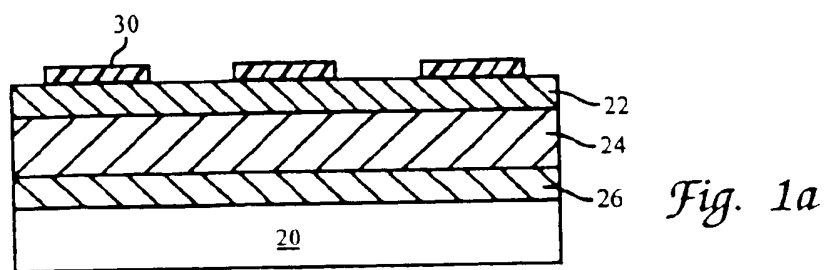
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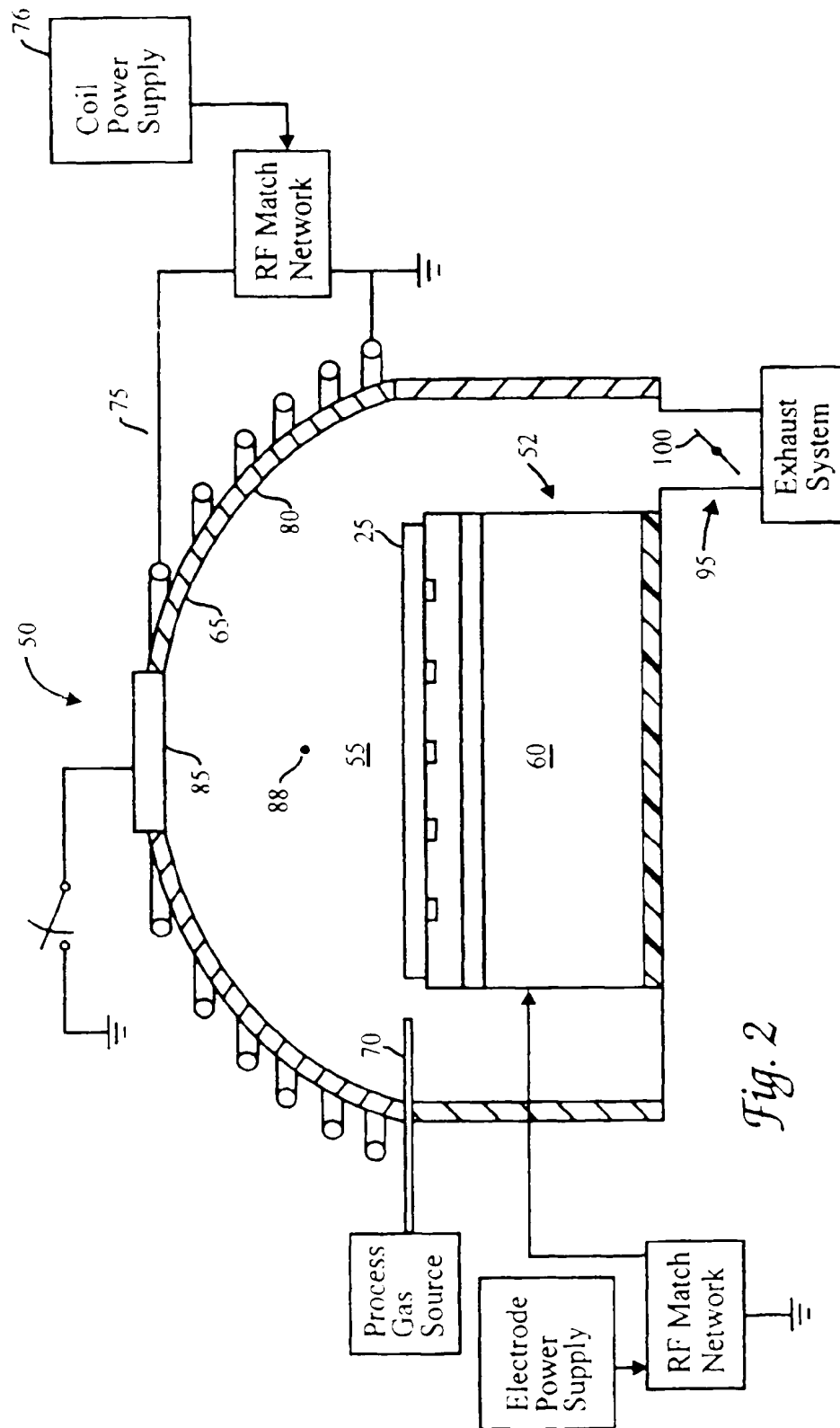


Fig. 2

Fig. 3

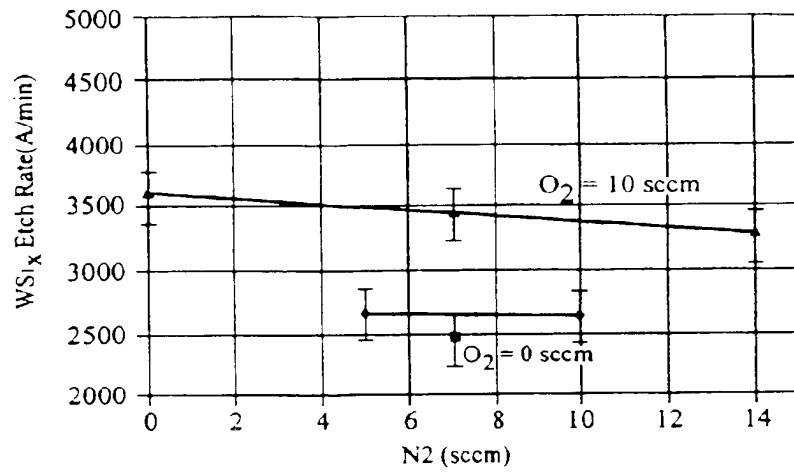


Fig. 4

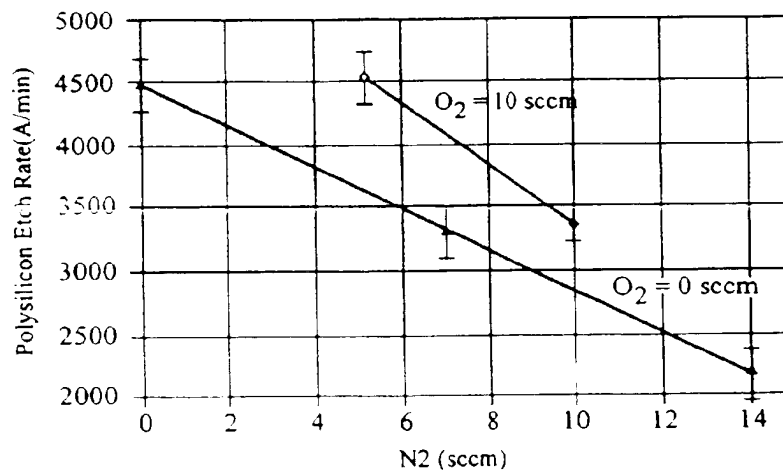
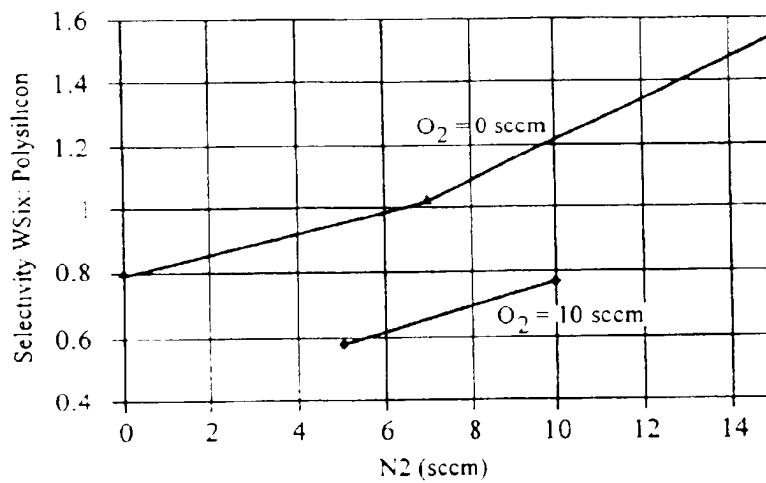
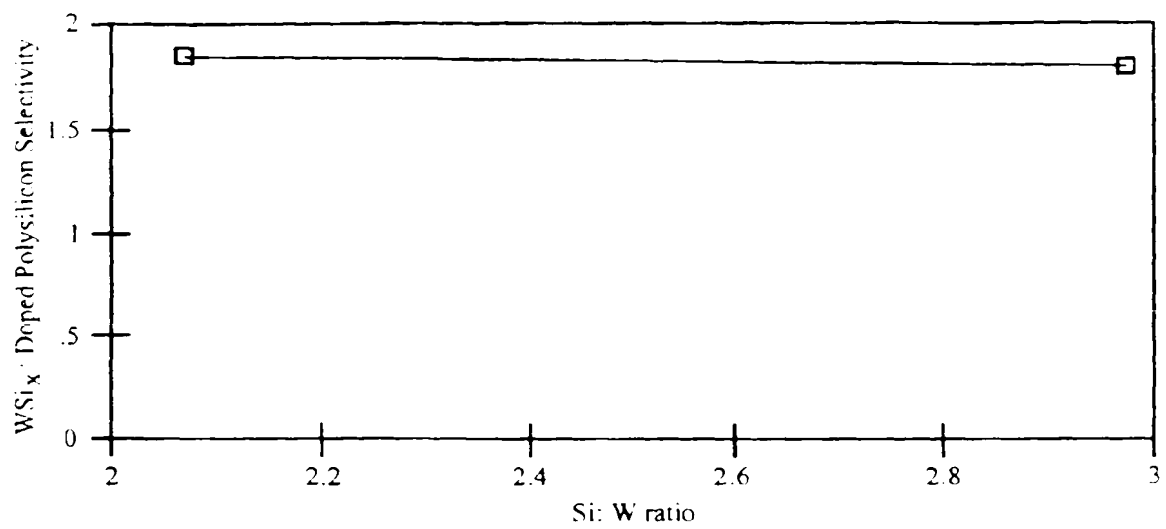
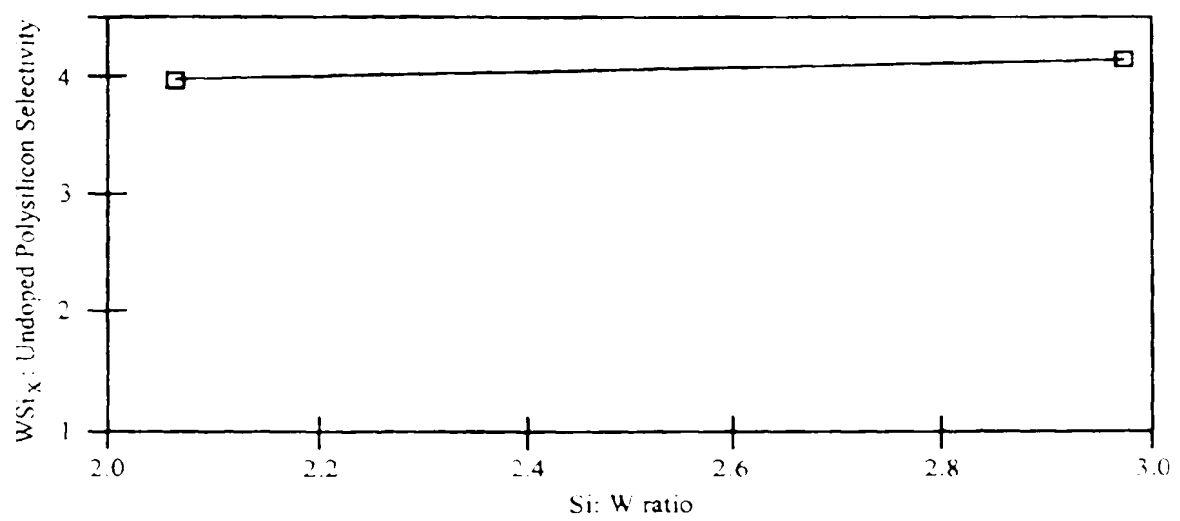
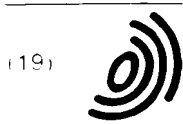


Fig. 5



*Fig. 6**Fig. 7*





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(54) Method for etching metal silicide with high selectivity to polysilicon

(57) A method for etching metal silicide layers 22a, 22b and polysilicon layers 24a, 24b on a substrate 20 with high etching selectivity and anisotropic etching properties is described. In the method, the substrate 20 is placed in a plasma zone 55 and process gas comprising Cl_2 , O_2 and N_2 is introduced into the plasma

zone. A plasma is formed from the process gas to selectively etch the metal silicide layer 22 at a first etch rate that is higher than a second rate of etching of the polysilicon layer 24 while providing substantially anisotropic etching of the metal silicide and polysilicon layers. Preferably, the plasma is formed using combined inductive and capacitive plasma sources.

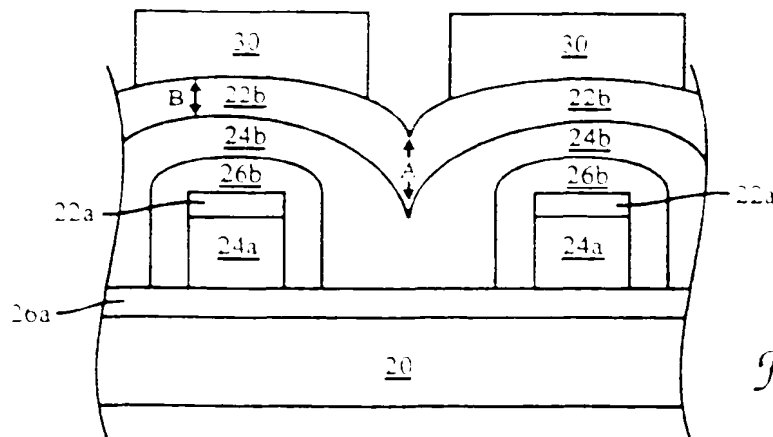


Fig. 1c

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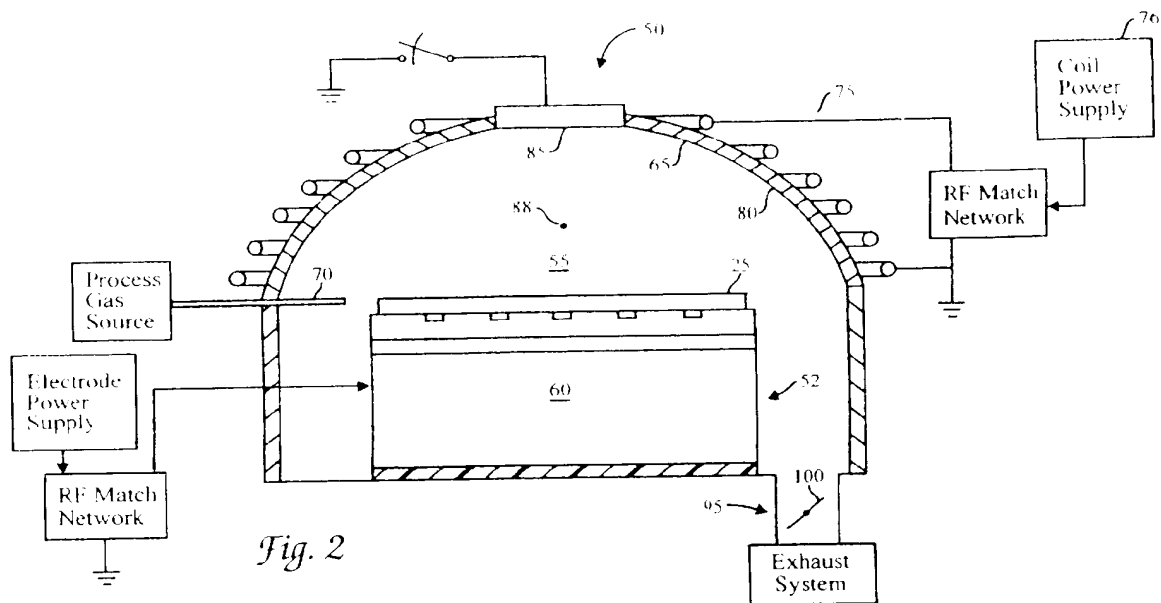


Fig. 2



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EUROPEAN SEARCH REPORT

Application Number
EP 97 30 4215

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Publication and document with a date on which it was made available to the public (date of publication)	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC Class)
A	GE 2 285 336 A (NIPPON ELECTRIC CO) * page 11, line 4 - line 14 *	1-9	H01L 21/321
A	EP 0 516 043 A (TOKYO ELECTRON LTD) * page 4, line 40 - line 53 * * page 5, line 18 - line 31 * * page 10, line 8 - page 11, line 55 * * claims 1,3,4,12 *	1	
A	US 5 338 398 A (SZWEJKOWSKI CHESTER A ET AL) * column 1, line 54 - line 68 * * column 2, line 44 - line 64 * * column 4, line 32 - line 51 * * claims 1-4 *		
A	US 4 411 734 A (MAA JER-SHEN) * column 3, line 36 - line 68 * * claim 1 *	1	
A	US 4 460 435 A (MAA JER-SHEN) * example 1 *	1	
			TECHNICAL FIELDS SEARCHED (IPC Class) H01L

The present search report has been drawn up for a claim:

THE HAGUE

29 October 1997

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CATEGORY OF RELEVANCE

- X particularly relevant (taken alone)
- Y particularly relevant (combined with another document of the same category)
- Z relevant (taken alone)
- W written disclosure
- P intermediate document

The relevant prior art underlying the invention is the state of the art as published on or after the filing date.

- D document cited in the application
- C document cited for other reasons

X members of the same patent family (corresponding document)

